

AUV Hydrodynamics in Shallow Water During Adverse Weather Conditions

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LONG-TERM GOALS

My long-term goal is to contribute an accurate hydrodynamics model to the design and development of robust and efficient autonomous underwater vehicles for naval and oceanographic applications in littoral waters. From a scientific viewpoint, the development of the hydrodynamics model would also lead to a better understanding of wave-body-current interactions and turbulent flows about underwater- and surface-vehicles.

OBJECTIVES

The hydrodynamics models used in the existing algorithms for controlling AUV motions are mostly based on the analysis of vehicle motion in infinite waters, *i.e.*, not including the effects of surface waves and bottom boundary on the vehicle dynamics. These models are inadequate for AUV operations in shallow waters where the boundary effects are significant. The objective of this project is to develop and test a robust hydrodynamics/dynamics model, including the effects of surface waves and bottom boundary, for the purpose of nowcasting and enhancing the performance of AUVs in shallow littoral waters. The hydrodynamics model will be of use even in deep-water applications, as AUVs continually operate close to the surface while seeking GPS *fixes* for navigation purposes.

APPROACH

We tackle the complex nonlinear wave-vehicle hydrodynamics problem using computational methods. Specifically, we have developed robust algorithms based on finite-difference and boundary-integral methods to determine wave exciting forces, vehicle response to wave forces, wave and viscous drag, hydrodynamic forces due to unsteady vehicle motion, and forces due to AUV and seabed interactions. The forces will be determined for a wide spectrum of parameters and sea states expected to be encountered in AUV missions in littoral waters. The computed forces will be decomposed in terms of hydrodynamic coefficients which can be integrated into AUV software to control vehicle motions in a straightforward manner. Laboratory experiments using scale models of small AUVs and prototypical micro AUVs are planned to validate the hydrodynamics model. Upon integration into OEX- and mini-AUV controller algorithms, field studies will be carried out to test the hydrodynamics model.

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WORK COMPLETED

(1) AUV Rigid-Body Dynamics: Robust numerical solvers have been developed for the solution of six-degree-of-freedom (6DOF) rigid-body dynamics equations to determine the response of the vehicle to specified propeller, fin and fluid forces. The solvers are particularly useful for investigating the dynamic stability and maneuverability of the AUVs. A preliminary analysis of the stability and maneuverability has been carried for the new ultra-modular mini AUVs that are under development at the Florida Atlantic University.

(2) Inviscid Hydrodynamics Analysis of AUV Motion: Efficient algorithms based on the boundary integral (*panel*) method have been successfully developed to investigate the inviscid hydrodynamics of AUVs in deep water. Using the *method of images*, we have also extended the method to compute the interaction forces as the vehicle moves close to the sea floor. Gertler geometry, upon which Florida Atlantic University's Ocean EXplorer (OEX) AUV hull shapes are based, are used for the simulations. The computations have been successfully completed for all six degrees of AUV motion in deep water as well as at various heights above the sea floor. The computation of the added-mass coefficients for the OEX in infinite water has also been successfully completed. The computed forces due to interaction between the AUV and sea bottom have been *curve-fitted* to obtain a simple hydrodynamics model, based on algebraic formulas, which can be readily integrated into controller algorithms.

(3) Finite-Difference Method for Viscous Hydrodynamics Analysis: The development of higher-order accurate two-dimensional finite-difference algorithms have been completed, and extension to three dimensions in progress, to determine the diffraction forces, excited by incident waves, and the radiation forces, caused by vehicle oscillations, in shallow waters. The governing Navier-Stokes equations are solved in the time domain using a fractional-step method. For accuracy, the finite-difference algorithms are implemented using boundary-fitted coordinates. The wave diffraction analysis has been carried out for a range of incident-wave parameters and the wave radiation analysis for a range of amplitude, frequency and modes of vehicle motions. Gertler profiles were used in the numerical simulations.

RESULTS

(1) AUV Rigid-Body Dynamics: Open-loop simulations of planar motions were performed for the OEX-AUV vehicle subjected to specified propeller and lateral thruster forces. The course-keeping ability of the vehicle, subject to external perturbations, was also examined. Representative results, reported in [1], have shown that a lateral thrust of approximately 10 [N] would be required to execute a turning circle of radius approximately 10 [m] while moving at a forward speed of approximately 2 [m/sec]. When laterally perturbed, as the vehicle is advancing forward at about 2.0 [m/s], our calculations show that it would take about 5 [mins] for the drift angle and lateral velocity of the vehicle to decay to negligibly small values. The angle of heading however would turn to about 4 [deg] from the original direction of translation. Such calculations were of use in the preliminary design of ultra-modular mini-AUVs which are under development at the Florida Atlantic University.

(2) Inviscid Hydrodynamics Analysis of AUV Motion: Using the special panel-method algorithms developed for the AUV project, we were able to successfully compute the added-mass coefficients for the OEX vehicle [1]. The coefficients were used to determine the inviscid inertia forces on the vehicle. Hydrodynamic simulation of the vehicle motion above the sea floor, have shown that the interaction (suction) force exerted on the vehicle could be significant when the vehicle is operating within a height

of one-body length above the sea floor [2]. For example, a Gertler-shaped vehicle of 2 [m] length advancing at 1 [m/s] at 0.3 [m] above the sea floor would experience a suction force of approximately 4 [N]. These estimates and analysis are of considerable value in the design of thrusters needed for hovering-type maneuvers above the sea floor.

(3) Viscous Hydrodynamics Analysis of AUV Motion in Waves: Using the boundary-fitted coordinates based finite-difference method, we have computed the hydrodynamic forces due to diffraction and radiation of waves associated with AUVs in shallow waters. Wave exciting forces are computed for a range of incident-wave parameters and depths of vehicle submergence [2]. We observe the generation of steep waves over the vehicle and the excitation of large wave forces on the vehicle, when the vehicle is close to the free surface (see Fig. 1). Interestingly, time-averaged hydrodynamic force reveals a *negative (up-wave) drift force* when the body is close to the free surface, a finding that is rather counter-intuitive! The wave radiation problem was analyzed for heave and surge modes of AUV motion near the free surface [3]. Our results have shown that the flow around the vehicle is highly vortical at high frequency of vehicle oscillation. Surprisingly, the flow around the body is found to be less vortical at low frequency of oscillation (see Fig. 2). A careful examination has shown that the vorticities generated on the body are swept off the body by the long waves generated at low frequency of body oscillation, thereby suppressing the inception of vortices. Our force calculations have shown that the surge component of the hydrodynamic force acting on the heaving vehicle is small compared to the heave component. However, the heave component of the hydrodynamic force acting on the surging vehicle is of the same order of magnitude as the surge force. Interestingly, it was also found that the frequency of heave force acting on the surging near-surface vehicle is twice that of the vehicle oscillation! This finding demonstrates the significance effect of the wave nonlinearity on near-surface vehicles.

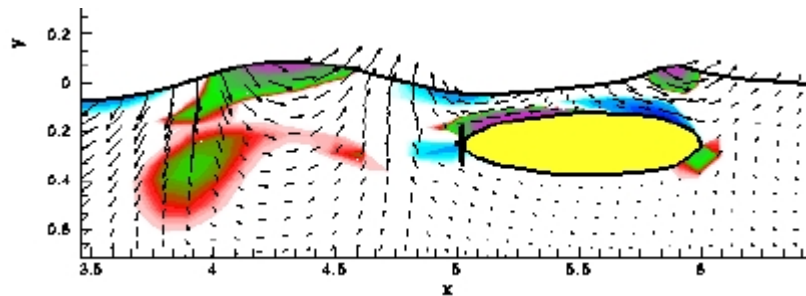


Fig 1. *Diffraction of waves over the slightly-submerged vehicle: velocity and vorticity fields.*

IMPACT/APPLICATIONS

- (1) The development of the hydrodynamics model for AUVs in a rigorous manner, as pursued in the present research, would lead to the development of robust controller algorithms and efficient propulsion systems for missions in littoral waters. The model can be used as a reliable tool for nowcasting the AUV performance in a given sea state, prior to carrying out the actual mission.
- (2) The hydrodynamics model, once validated and proven accurate, has the potential to become a standard routine in the design software for AUVs and other submerged vehicles.

(3) From a scientific viewpoint, the analysis carried out in this research will raise our level of understanding of basic fluid-body interactions in the presence of waves and currents and in the vicinity of the sea floor, and contribute to the development of turbulence models.

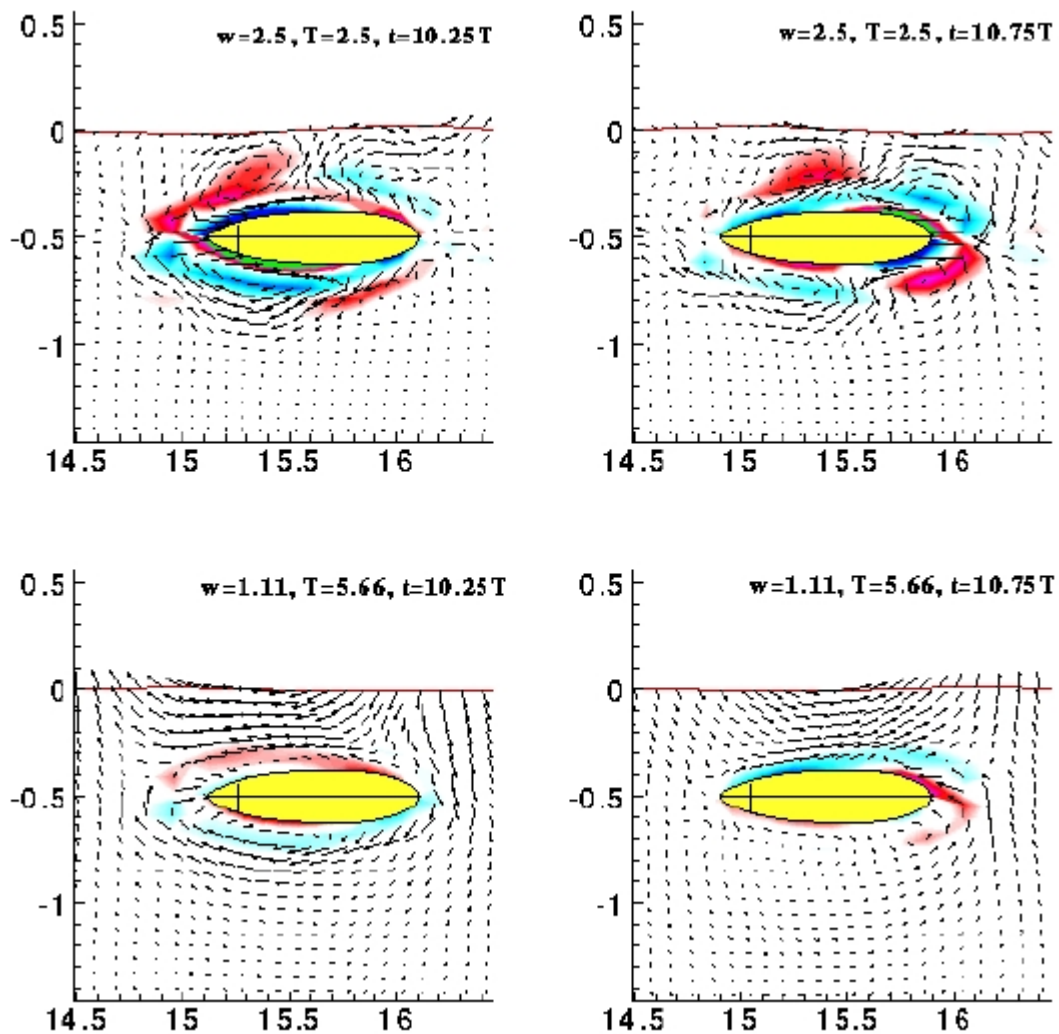


Fig. 2. Velocity and vorticity fields corresponding to surge oscillation at high frequency (top row) and low frequency (bottom row).

TRANSITIONS

The present AUH hydrodynamics/dynamics model has been used in the preliminary design of mini-, ultra-modular AUVs under development at the Florida Atlantic University.

RELATED PROJECTS

The PI is assisting the Advanced Marine Systems Group of the Department of Ocean Engineering at Florida Atlantic University in the design of propellers for OEX II-AUV [4]. The AUV hydrodynamics

model is expected to shed some light on hull-propeller interactions, an accurate quantification of which is necessary for the design of more efficient propellers in the future.

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